

# **ARIES-IFE Assessment of Operational Windows for IFE Power Plants**

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Electronic copy: <http://aries.ucsd.edu/najmabadi/TALKS>  
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# ARIES Integrated IFE Chamber Analysis and Assessment Research Is An Exploration Study

## Objectives:

- Analyze & assess integrated and self-consistent IFE chamber concepts
- Understand trade-offs and identify design windows for promising concepts.  
*The research is **not** aimed at developing a point design.*

## Approach:

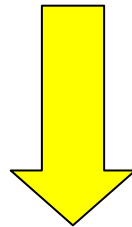
- Six classes of target were identified. Advanced target designs from NRL (laser-driven direct drive) and LLNL (Heavy-ion-driven indirect-drive) are used as references.
- To make progress, we divided the activity based on three classes of chambers:
  - Dry wall chambers;
  - Solid wall chambers protected with a “sacrificial zone” (e.g., liquid films);
  - Thick liquid walls.

ARIES-IFE study was completed in September 2003.

# Outline

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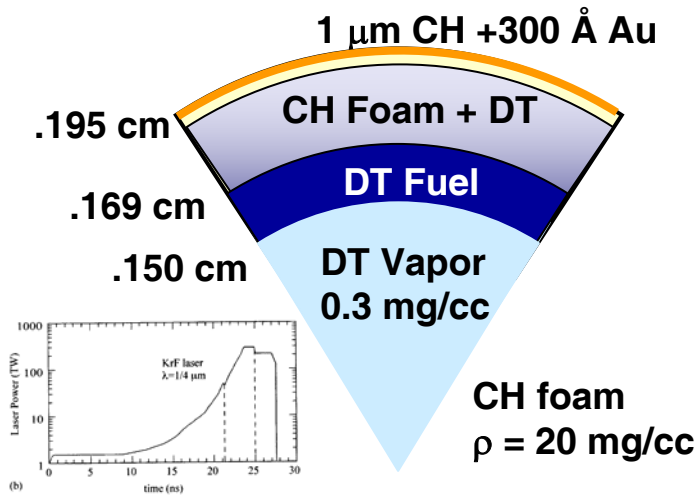
- Target Design
- Target emission spectra and energy and particle loads on the chamber wall
- Thermo-mechanical response of the chamber wall
- Target survival during injection
- Driver propagation and focusing in the chamber



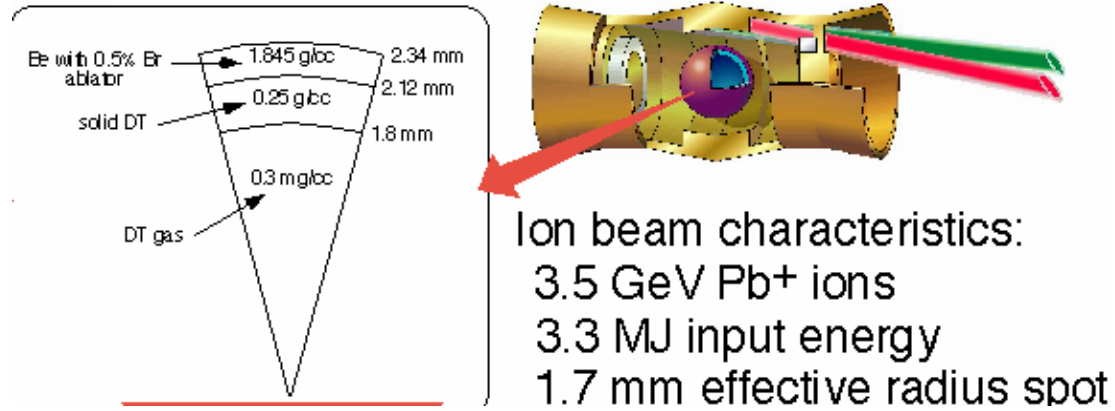
Operational Windows

# Reference Direct and Indirect Target Designs

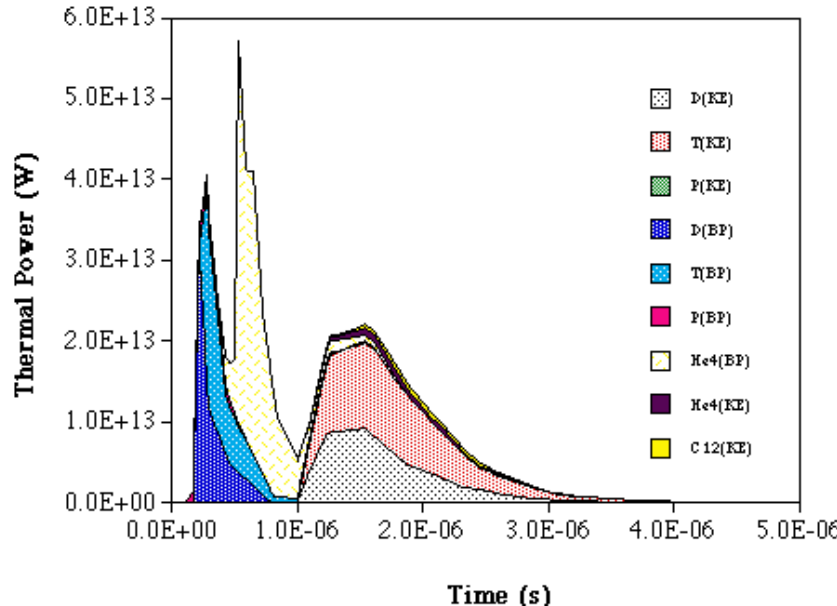
## NRL Advanced Direct-Drive Targets



## LLNL/LBNL HIF Target



### Time-of-Flight Ion Power Spread



	Direct-Drive Target		Indirect-Drive Target	
	Energy (MJ)	% of yield	Energy (MJ)	% of yield
Driver Energy	1.3		3.3	
Total Yield	154		458	
Neutrons	109	71 %	316	69 %
Fast Ions	18.1	12 %	8.43	1.8 %
Debris Ions	24.9	16 %	18.1	4.0 %
X-rays	2.14	1.4 %	115	25 %

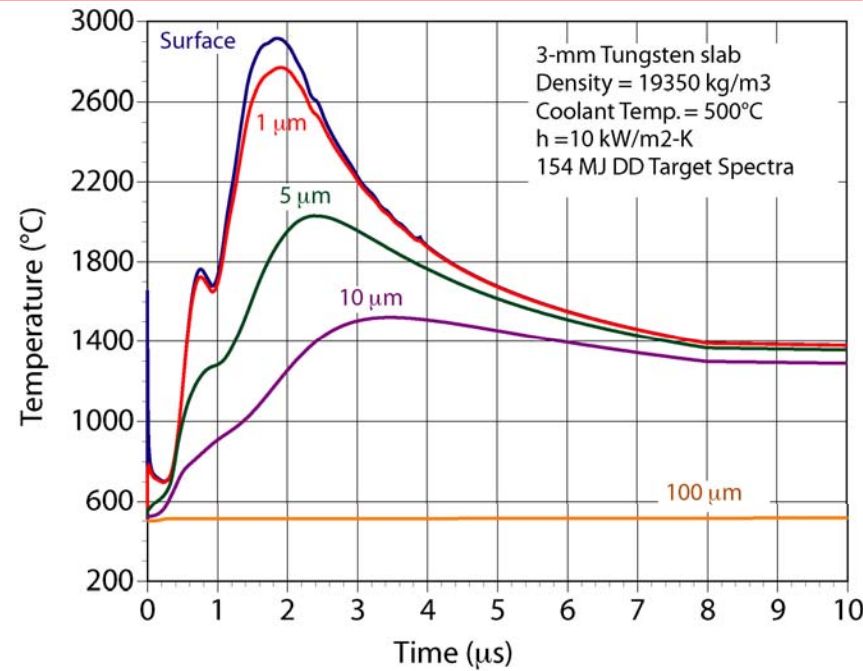
# Dry-wall chamber can handle direct-drive target emissions

- Photon and ion energy deposition falls by 1-2 orders of magnitude within 0.1-0.2 mm of surface.
- Beyond the first 0.1-0.2 mm of the surface. First wall experiences a much more uniform  $q''$  and quasi steady-state temperature (heat fluxes similar to MFE).

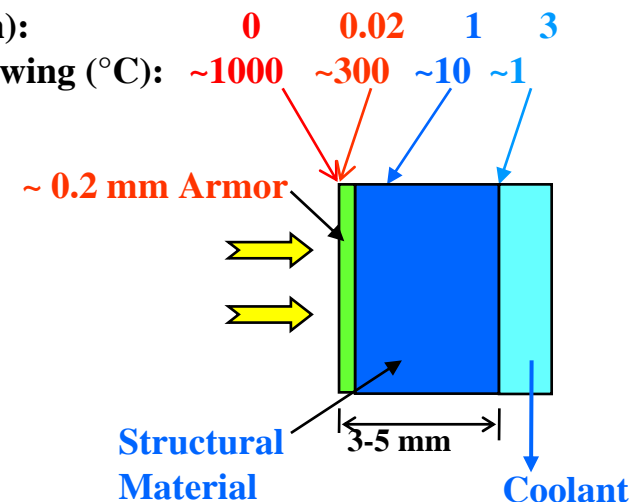
## ➤ Use an Armor

- ✓ Armor optimized to handle particle & heat flux.
- ✓ First wall is optimized for efficient heat removal.

- Critical Issue is the lifetime of the armor:
  - ✓ He retention and exfoliation
  - ✓ Cyclic Fatigue
  - ✓ De-bonding of the armor



Depth (mm): 0 0.02 1 3  
Typical T Swing (°C): ~1000 ~300 ~10 ~1



# Aerosol Generation and Transport is the Key Issue for Thin-Liquid Wall Concepts

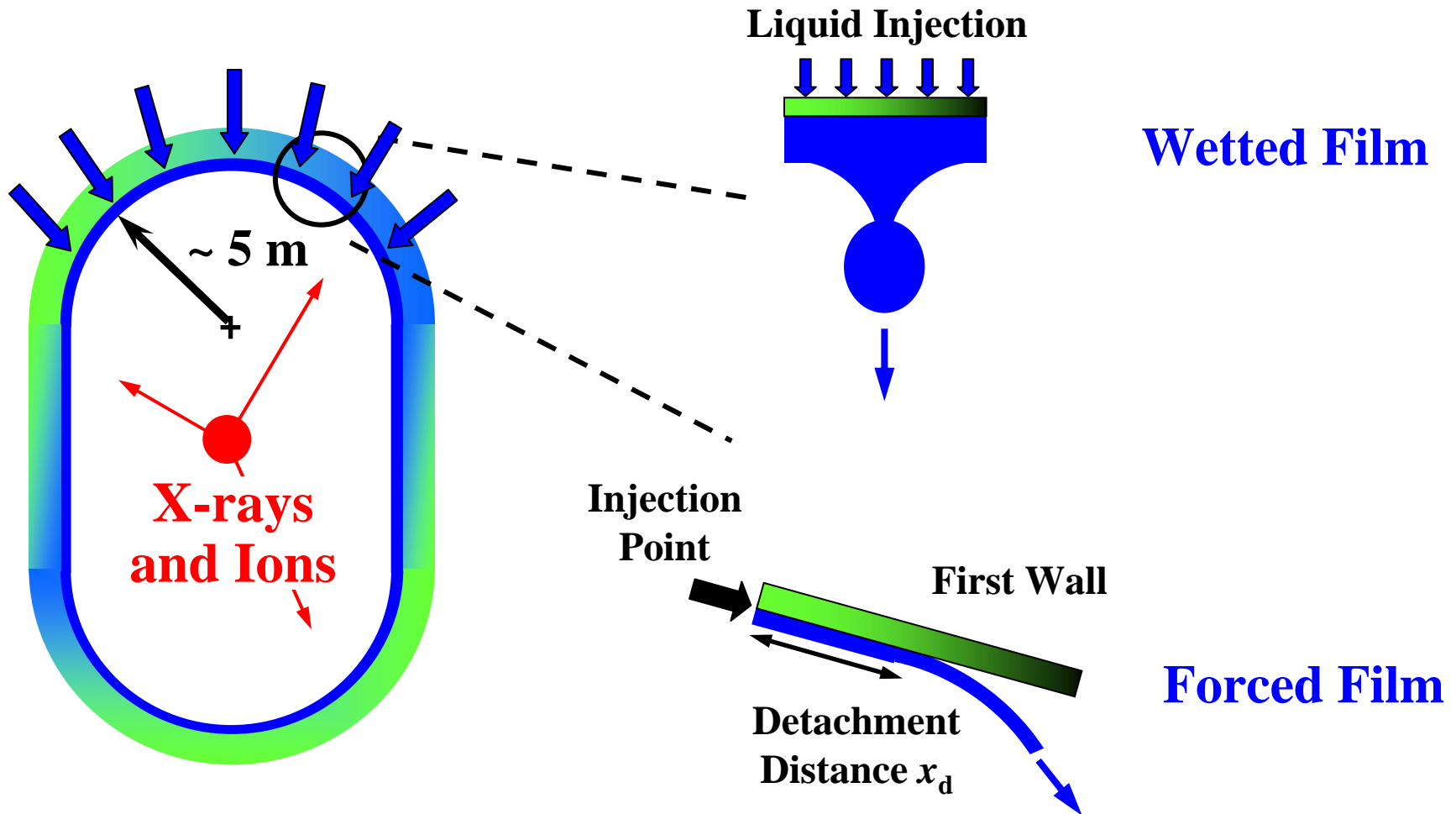
A renewable thin-liquid protection resolve several issues:

- It can handle a much higher heat fluxes compared to solid surfaces;
- It will eliminate damage to the armor/first wall due to high-energy ions.

A renewable thin-liquid protection, however, introduces its own critical issues:

- Fluid-dynamics aspects (establishment and maintenance of the film)
  - ✓ “Wetted wall:” Low-speed normal injection through a porous surface
  - ✓ “Forced film:” High-speed tangential injection along a solid surface
- Chamber clearing (recondensation of evaporated liquid)
  - ✓ “Source term:” both vapor and liquid (e.g., explosive boiling) are ejected
  - ✓ Super-saturated state of the chamber leads to aerosol generation
  - ✓ Target injection and laser beam propagation lead to sever constraints on the acceptable amount and size of aerosol in the chamber.

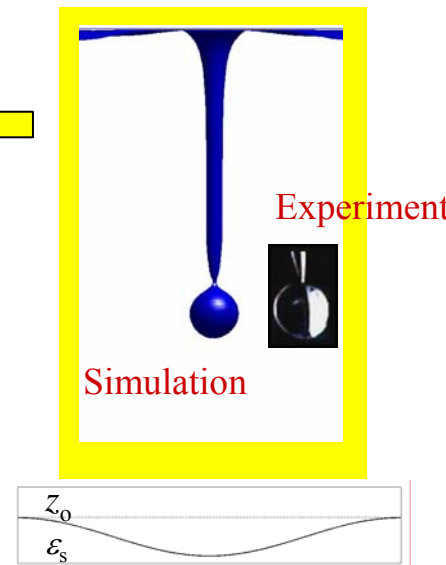
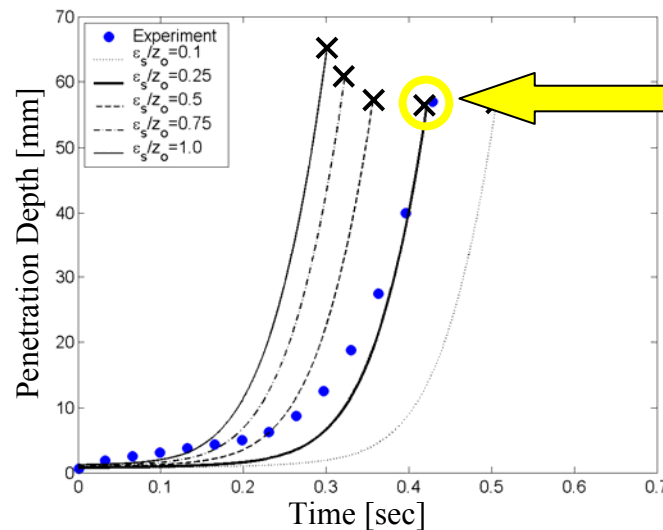
# Two Methods for Establishment of Thin-Liquid Walls Have Been Proposed





# A Thin-Liquid Protected Film can be Established and Maintained

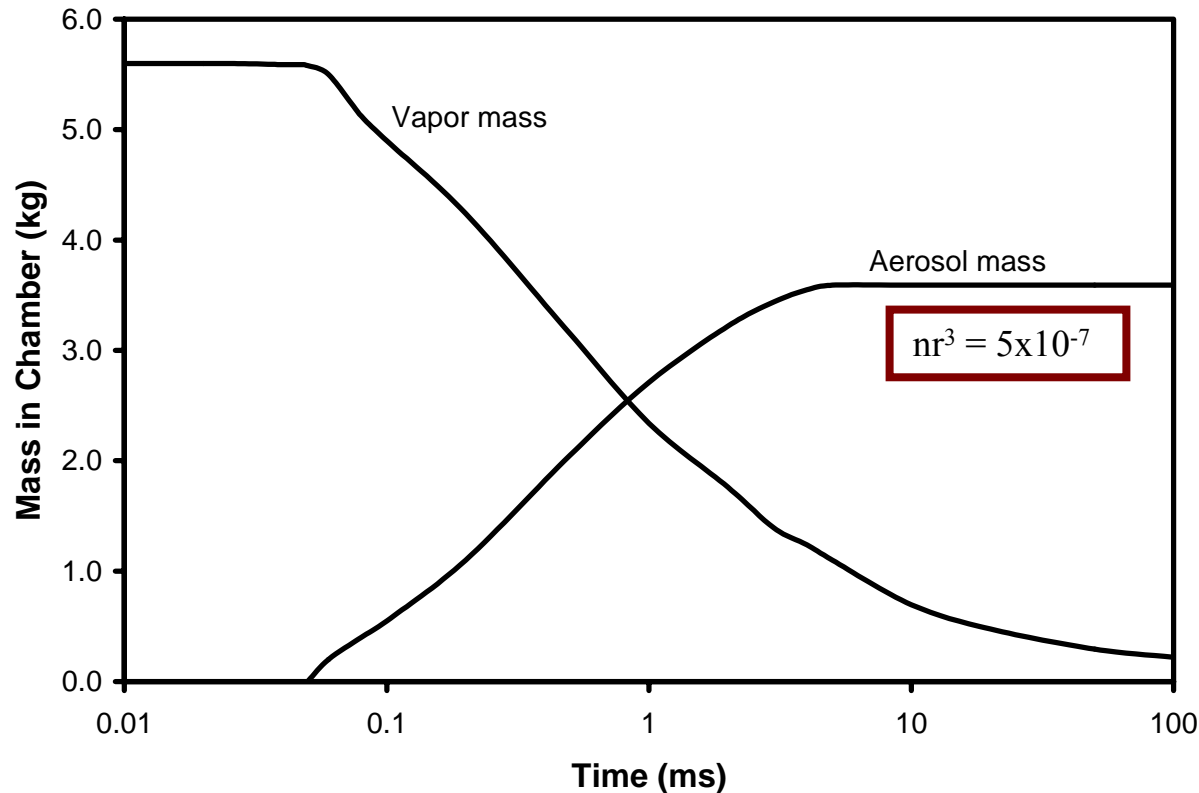
- Developed general non-dimensional charts for film stability
- Model predictions are closely matched with experimental data.



- Radial injection scheme appear to be feasible and does not impose major constraints. Attractiveness of this concept depends on:
  - ✓ Details on the chamber and power plant design
  - ✓ Impact of the required pumping power on the recirculating power & overall economics
- For the forced-flow scheme, behavior of the film near major obstacles is a major concern

# Most of Ablated Material Would Be in The Form of Aerosol

- FLiBe aerosol and vapor mass history in a 6.5-m radius chamber (ablated thickness of 5.5 mm)
- Only homogeneous nucleation and growth from the vapor phase.

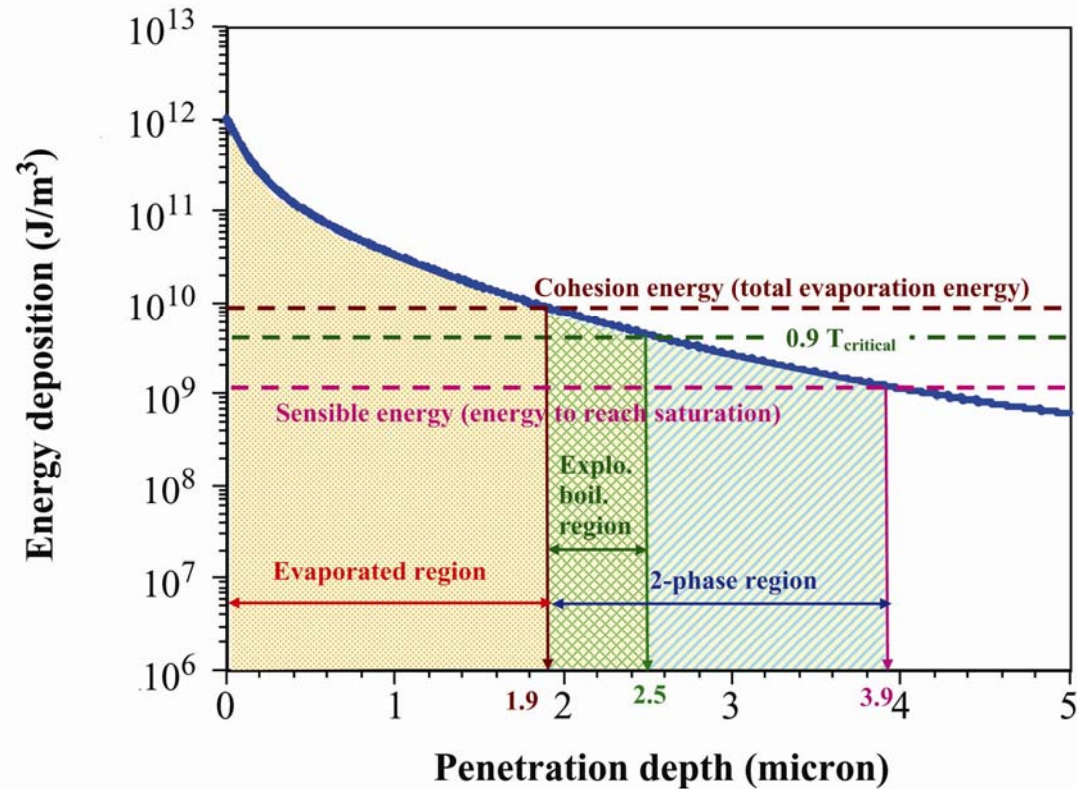


- Most of ablated material remains in the chamber in aerosol form;

- Similar analysis for a 3-m chamber radius leads to 1.8 kg aerosol mass but higher  $nr^3 = 8 \times 10^{-6}$

# There Are Many Mechanism of Aerosol Generation in an IFE Chamber

- Homogeneous nucleation and growth from the vapor phase
  - ✓ Supersaturated vapor
  - ✓ Ion seeded vapor
- Phase decomposition from the liquid phase
  - ✓ Thermally driven phase explosion
  - ✓ Pressure driven fracture
- Hydrodynamic droplet formation (May be critical in Thick-liquid Wall concepts")



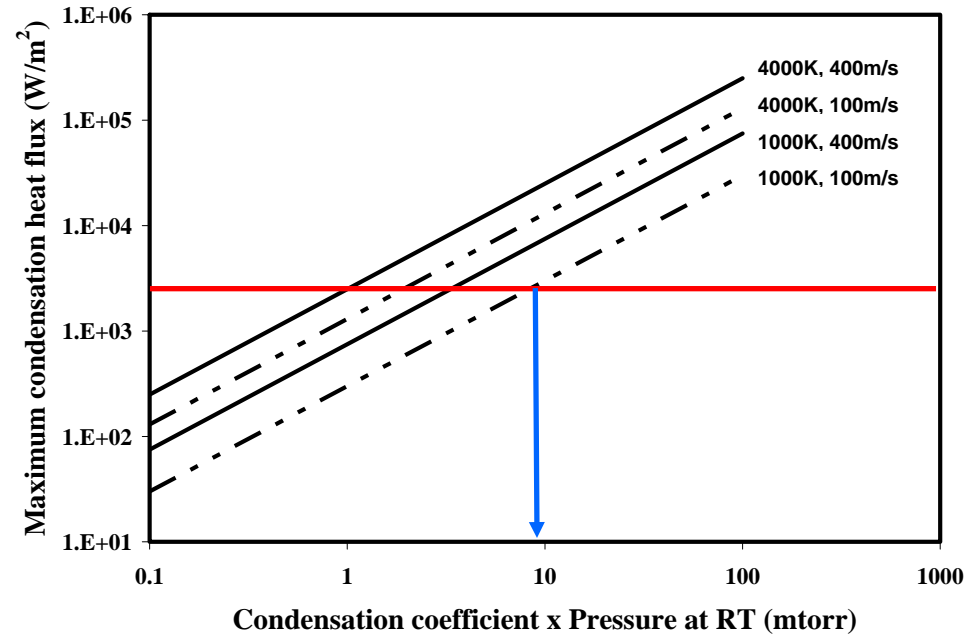
# Aerosol Generation and Transport is also the Key Issue for Thick-Liquid Wall Concepts

- Studies of structural materials choices and limits
  - ✓ If a 300 series SS is required as a near-term base line for the design, then Ti-modified 316SS (PCA) should be used. Chamber vessel would not be a life-time components.
  - ✓ However, it was strongly recommended to consider alternate structural material candidates (ferritic steels and SiC/SiC composites) offering the possibility of higher operating temperature & performance. In this case, chamber vessel may be a life-time component.

- Aerosol concerns (similar to thin liquids) were highlighted.
  - ✓ Hydrodynamic droplet formation is a key issue. Flow conditioning and careful nozzle design are needed to control the hydrodynamic source.

# Target injection Design Window Naturally Leads to Certain Research Directions

- Direct-drive targets (initial  $T=18\text{K}$ ) are heated during their travel in the chamber by:
  - Friction with the chamber gas (mainly through condensation heat flux) requiring
    - ✓ Lower gas pressure
    - ✓ Slower injection velocity
  - Radiation heat flux from hot first wall, requiring
    - ✓ Lower equilibrium temperature
    - ✓ Faster injection velocity
- Addition of a thin ( $\sim 70\mu\text{m}$ ) foam improves the thermal response considerably.



- Direct-drive target injection imposes the toughest constraint on chamber gas pressure.
- Impact of aerosol is unknown
- No constraint for indirect-drive targets

# Studies of Ion Transport Modes Indicate Several Options are Feasible

Transport Mode	Ballistic Transport <i>chamber holes ~ 5 cm radius most studied</i>		Pinch Transport <i>chamber holes ~ 0.5 cm radius higher risk, higher payoff</i>	
	<u>Vacuum-ballistic</u> <i>vacuum</i>	<u>Neutralized-ballistic</u> <i>plasma generators</i>	<u>Preformed channel</u> ("assisted pinch") <i>laser + z-discharge</i>	<u>Self-pinched</u> <i>only gas</i>
<u>Dry-wall</u> <i>~6 meters to wall</i>	<b>Not considered now:</b> requires ~500 or more beams	ARIES-IFE (2002) <b>Possible option:</b> but tighter constraints on vacuum and beam emittance	ARIES-IFE (2001) <b>OPTION:</b> uses 1-10 Torr  <i>2 beams</i>	ARIES-IFE (2001) <b>OPTION:</b> uses 1-100 mTorr  <i>~2-100 beams</i>
<u>Wetted-wall</u> <i>~ 4-5 meters to wall</i>	HIBALL (1981) <b>Not considered:</b> needs $\leq 0.1$ mTorr	OSIRIS-HIB (1992) ARIES-IFE (2002) <b>Possible option:</b> but tighter constraints on vacuum and beam emittance	ARIES-IFE (2001) <b>OPTION:</b> uses 1-10 Torr  <i>2 beams</i>	PROMETHEUS-H (1992) ARIES-IFE (2001) <b>OPTION:</b> uses 1-100 mTorr <i>~2-100 beams</i>
<u>Thick-liquid wall</u> <i>~ 3 meters to wall</i>	<b>Not considered:</b> needs $\leq 0.1$ mTorr	HYLIFE II (1992-now) ARIES-IFE (2002) <b>Main-line approach:</b> uses pre-formed plasma and 1 mTorr for 3 m <i>~50-200 beams</i>	ARIES-IFE (2002) <b>OPTION:</b> uses 1-10 Torr  <i>2 beams</i>	ARIES-IFE (2002) <b>OPTION:</b> uses 1-100 mTorr  <i>~2-100 beams</i>

$nr^3 \leq 10^{-9}$  (aerosol)  
or  $\sim 1$  mTorr (gas)

$nr^3 \leq 10^{-6}$  (aerosol)  
or  $\sim 1$  Torr (gas)

$nr^3 \leq 10^{-7}$  (aerosol)  
 $\sim 100$  mTorr (gas)

# Summary

## Dry wall chambers

- Laser and direct-drive targets:
  - ✓ Sever constraint on chamber gas pressure (from target injection).
  - ✓ Wall can survive without any gas protection
  - ✓ The major issue is the lifetime of the armor
- Laser or heavy-ions and indirect-drive targets:
  - ✓ Required protection gas pressure may be too high for laser and/or heavy-ion propagation
  - ✓ Recycling of hohlraum material is a major issue.

## Wetted-wall and Thick-liquid wall chambers

- Heavy-ion and indirect-drive targets:
  - ✓ Requires assisted pinch propagation
  - ✓ Aerosol generation and transport is a major issue.